

## Micronized Coal Reburning Demonstration for NO<sub>x</sub> Control

### Project completed

#### Participant

New York State Electric & Gas Corporation

#### Additional Team Members

Eastman Kodak Company—host and cofunder

CONSOL (formerly Consolidation Coal Company)—coal sample tester

D.B. Riley—technology supplier

Fuller Company—technology supplier

Energy and Environmental Research Corporation EER)—reburn system designer

New York State Energy Research and Development Authority—cofunder

Empire State Electric Energy Research Corporation—cofunder

#### Locations

Lansing, Tompkins County, NY (New York State Electric & Gas Corporation's Milliken Station, Unit No. 1)

Rochester, Monroe County, NY (Eastman Kodak Company's Kodak Park Power Plant, Unit No. 15)

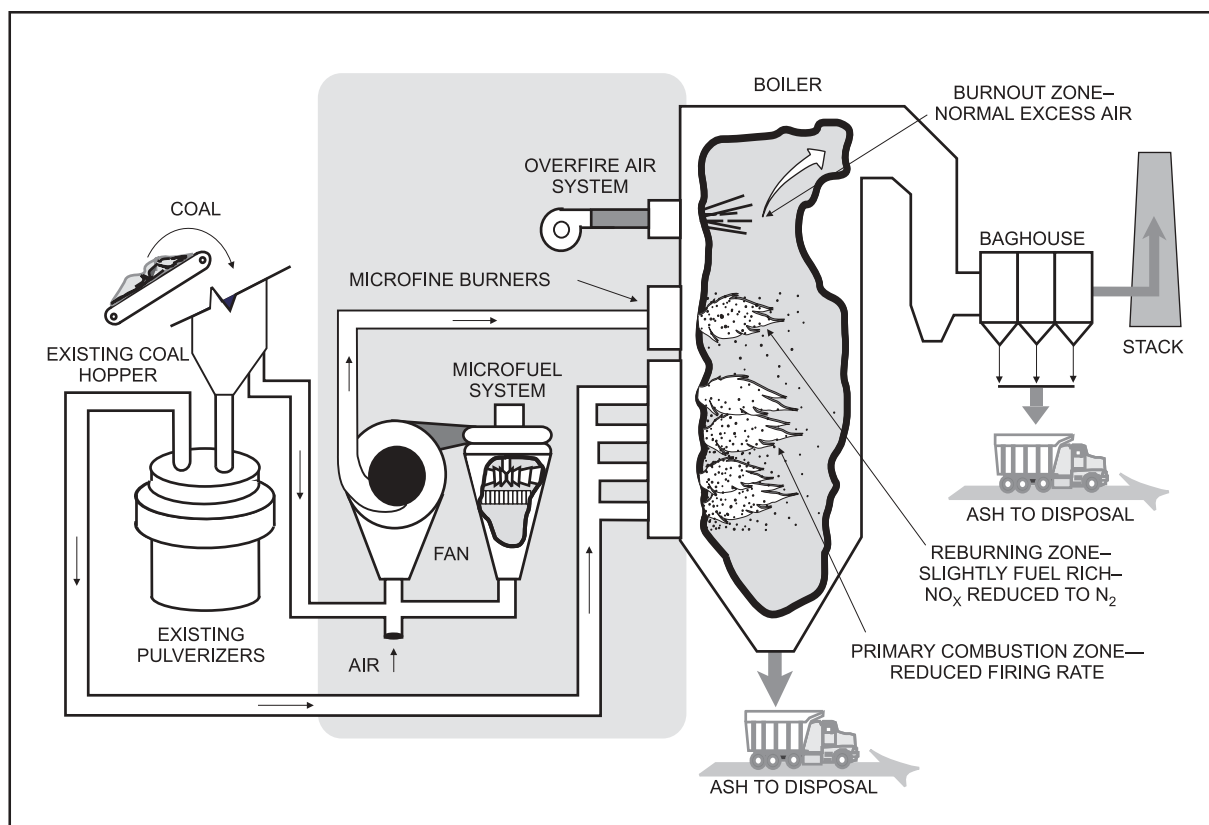
#### Technology

D.B. Riley's MPS mill (at Milliken Station) and Fuller's MicroMill™ (at Eastman Kodak) technologies for producing micronized coal

#### Plant Capacity/Production

Milliken Station: 148-MWe tangentially fired boiler

Kodak Park: 60-MWe cyclone boiler



#### Coal

Pittsburgh seam bituminous, medium- to high-sulfur (3.2% sulfur and 1.5% nitrogen at Milliken and 2.2% sulfur and 1.6% nitrogen at Kodak Park)

#### Project Funding

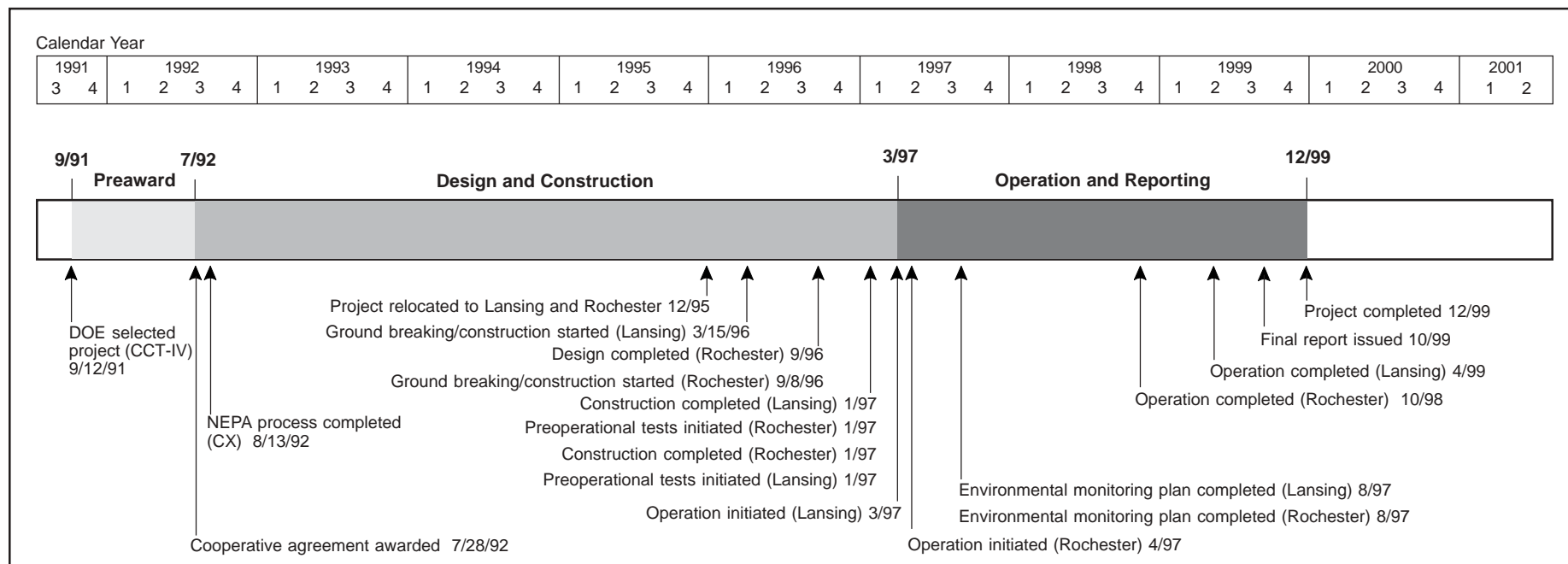
Total project cost	\$9,096,486	100%
DOE	2,701,011	30
Participant	6,395,475	70

#### Project Objective

To achieve at least 50% NO<sub>x</sub> reduction with micronized coal reburning technology on a cyclone boiler, to achieve 25–35% NO<sub>x</sub> reduction with micronized coal reburning technology in conjunction with low-NO<sub>x</sub> burners on a tangentially fired boiler, and to determine the effects of coal micronization on electrostatic precipitator (ESP) performance.

#### Technology/Project Description

The reburn coal, which can constitute up to 30% of the total fuel, is micronized (pulverized to achieve 80% below 325 mesh) and injected into a pulverized coal-fired furnace above the primary combustion zone. At the Milliken tangentially fired boiler site, NO<sub>x</sub> control is achieved by: (1) close-coupled overfire air (CCOFA) reburning in which the top coal injector of the LNCFS III™ burner is used for injecting the micronized coal, and the separated overfire air system completes combustion; and (2) the remaining burners and air ports are adjusted for deep-stage combustion by re-aiming them to create a fuel-rich inner zone and fuel-lean outer zone providing combustion air. At the Kodak Park cyclone boiler site, the Fuller MicroMill™ is used to produce the micronized coal, reburn fuel is introduced above the cyclone combustor, and overfire air is employed to complete the combustion.



## Results Summary

### Environmental

- Using a 14.4% reburn fuel heat input on the Milliken Station tangentially fired boiler at full load resulted in a  $\text{NO}_x$  emission rate of 0.25 lb/10<sup>6</sup> Btu, which represents a 29%  $\text{NO}_x$  reduction from the 0.35 lb/10<sup>6</sup> Btu achieved with the LNCFS III™ burner alone (baseline).
- Using a 17.3% reburn fuel heat input (reburn stoichiometry of 0.89) on the Kodak Park cyclone boiler resulted in a  $\text{NO}_x$  emission rate of 0.59 lb/10<sup>6</sup> Btu, which represents a 59%  $\text{NO}_x$  reduction from 1.36 lb/10<sup>6</sup> Btu (baseline). Higher reburn rates (estimated at 18.4% reburn or stoichiometry of 0.87) would be required for long-term compliance with 0.60 lb/10<sup>6</sup> Btu  $\text{NO}_x$  emission limits.

### Operational

- Reburning was successfully applied at Milliken Station using the top coal feed of the LNCFS III™ burner for the reburn fuel and reducing the top burner level air flows. This eliminated the need for a separate reburn

system. Testing on the tangentially fired boiler at Milliken Station showed:

- Unburned carbon-in-ash, also referred to as loss-on-ignition (LOI), was maintained under 5%;
- Increasing the economizer  $\text{O}_2$  generated the classical response of higher  $\text{NO}_x$  emissions and lower LOI—the sensitivity was estimated at 0.1 lb/10<sup>6</sup> Btu per 1% change in  $\text{O}_2$  and was relatively independent of coal fineness;
- Increasing coal fineness reduced both  $\text{NO}_x$  emissions and LOI—the effect on  $\text{NO}_x$  was significant only for large variations in coal fineness; and
- Pulverizing the reburn coal to the micronized level (greater than 80% passing 325 mesh) was not a requirement for the successful application of reburning, but significantly impacted LOI.
- Testing on the cyclone boiler at Kodak Park showed:
  - The reburn stoichiometry had a significant effect on  $\text{NO}_x$  emissions and a significant effect on LOI—lower reburn stoichiometries reduced  $\text{NO}_x$  emissions and increased LOI to 40–45% compared with a LOI baseline of 10–15%.

- Short-term testing indicated that LOI could be maintained at levels similar to baseline levels without significantly affecting  $\text{NO}_x$  emissions by maintaining a baseline cyclone heat input.

### Economic

- The estimated capital cost for retrofitting a generic 300-MWe tangentially fired boiler with micronized coal reburning is \$4.3 million, or approximately \$14/kW (1999\$). The corresponding O&M costs are estimated at \$0.30 million per year (1999\$). The resulting total 15-year levelized cost is \$1,329/ton of  $\text{NO}_x$  removed (current 1999\$) or \$1,023 (constant 1999\$).
- The estimated capital cost for retrofitting a generic 300-MWe cyclone boiler with micronized coal reburning is \$16.9 million, or approximately \$56/kW (1999\$). The corresponding O&M costs are estimated at \$0.80 million per year (1999\$). The total 15-year levelized cost is \$741/ton of  $\text{NO}_x$  removed (current 1999\$) or \$571 (constant 1999\$).

## Project Summary

NYSEG demonstrated the micronized coal reburning technology in both tangentially fired and cyclone boilers. The tangentially fired boiler was NYSEG's Milliken Station 148-MWe tangentially fired Unit No. 1 (also the host for another CCT Program demonstration). The cyclone boiler was Eastman Kodak Company's Kodak Park Power Plant 60-MWe cyclone Unit No. 15.

The challenge with this coal reburning demonstration was to achieve adequate combustion of the reburn coal in the oxygen-deficient, short-residence-time reburn zone to reduce  $\text{NO}_x$  emissions without detrimentally increasing the unburned carbon in the ash, *i.e.*, loss-on-ignition. The primary objective of this two-site project was to demonstrate improvements in coal reburning for  $\text{NO}_x$  emission control by reducing the particle size of the reburn coal. In this demonstration, the coal was finely ground to 80% or more passing 325 mesh and injected into the boilers above the primary combustion zone. The resulting typical particle size is 20 microns compared to 60 microns for normal pulverized coal particles. This smaller size increases surface area ninefold.

With this increased surface area and coal fineness (micronized coal has the combustion characteristics of atomized oil), carbon combustion occurs in milliseconds and volatiles are released at an even rate.

### Operating Performance

At the Milliken Station, the existing ABB Low- $\text{NO}_x$  Concentric Firing System™ (LNCFS-III), which includes both close coupled and separated overfire air (SOFA) ports, was used for the reburn demonstration. Four D.B. Riley MPS 150 mills with dynamic classifiers provided the pulverized coal. With LNCFS-III, there are four levels of burners. To simulate and test the coal reburning application, the top-level coal injection nozzles fed micronized coal to the upper part of the furnace for this demonstration. The coal injection nozzles at the three lower elevations were biased to carry approximately 80% of the fuel required for full load. The speed of the dynamic classifier serving the mill feeding the top burners was increased to produce the micronized coal (greater than 80% passing 325 mesh).

During the evaluation, several conclusions were reached on how operating variables affected performance. While maintaining a constant economizer  $\text{O}_2$  level, no single operating variable had a dominant effect on reburning performance. A combination of operating settings determined from short-term testing were selected for long-term operation to achieve the lowest  $\text{NO}_x$  emissions and reliable operation. Operating settings for long-term operation were 14–16% reburn coal, 105 rpm top mill classifier speed (corresponds to 70–72% passing 325 mesh), –5 degrees main burner tilt and 2.8% economizer  $\text{O}_2$ . No additional improvement in LOI was observed at top mill classifier speeds above 105 rpm.

At Kodak Park, EER designed the micronized coal reburn system using a combination of analytical and empirical techniques. The reburn fuel and OFA injection components were designed with a high degree of flexibility to allow for field optimization to accommodate the complex furnace flow patterns in the cyclone boiler. Two Fuller MicroMills™ were installed in parallel on Kodak Park Unit No. 15 to provide the capacity necessary for high reburn rates, with the second mill serving as a spare at lower reburn rates. The mills produced the micronized coal reburn fuel at greater than 90% passing 325 mesh. Eight injectors, six on the rear wall and one on each of the side walls, introduced the micronized coal into the reburn zone. The optimization variables included the number of injectors, swirl, and velocity. Four ports on the front wall provided OFA using EER's second-generation, dual-concentric overfire air design, which has variable injection velocity and swirl. To maximize  $\text{NO}_x$  reduction, the reburn fuel was injected with flue gas rather than air. The flue gas was extracted downstream of the electrostatic precipitator and was boosted by a single fan. A new boiler control system was also installed on Unit No. 15.

### Environmental Performance

At the Milliken Station, micronized coal reburning with 14.4% reburn fuel at full load reduced  $\text{NO}_x$  emissions from the 0.35 lb/10<sup>6</sup> Btu baseline level to 0.25 lb/10<sup>6</sup> Btu, a 29% reduction. This reduction represents an addition to the 39% reduction achieved with the LNCFS III™ low- $\text{NO}_x$  burner alone. Boiler efficiency was maintained at 88.4–88.8%. Furthermore, concentrating the overfire air

through fewer and higher ports and using finer grind reburn coal maintained LOI below 5%. Based on long-term testing consisting of 23 days of continuous measurements, the achievable annual  $\text{NO}_x$  emissions using 15.1% coal reburn heat input were estimated at  $0.245 \pm 0.011$  lb/10<sup>6</sup> Btu (95% confidence), and the estimated average fly ash LOI was  $4.4 \pm 0.4\%$ . Based on replicated performance tests and a 95% confidence level, variations in  $\text{NO}_x$  emissions less than 0.006 lb/10<sup>6</sup> Btu and in fly ash LOI less than 1.5 percentage points were assumed to be of no statistical significance. There were large uncertainties with respect to the effects on LOI, possibly because LOI generally varied within a relatively narrow range (between 3% and 5%) in response to changing operating variables.

With regard to reburn coal fineness and reburn coal quantity, using a finer grind reburn coal (top mill) reduced both  $\text{NO}_x$  emissions and LOI. The effect on  $\text{NO}_x$  was significant (relative to the uncertainty level of 0.006 lb/10<sup>6</sup> Btu) only for relatively large variations in the top mill classifier speed (and hence coal fineness). Using a finer grind coal (all mills) reduced both  $\text{NO}_x$  emissions and LOI. Decreasing the reburn coal fraction from 25% to 14% decreased  $\text{NO}_x$  emissions from 0.25 to 0.23 lb/10<sup>6</sup> Btu and had a minor effect on LOI (generally less than 1.5 percentage points). The decrease in  $\text{NO}_x$  from decreasing the coal reburn fraction was attributed to lower excess air levels in the primary combustion zone as more coal was diverted to the lower burners.

Reducing the boiler load reduced  $\text{NO}_x$  emissions, and the effect was greater when the second mill was taken out of service. Thus, reducing the boiler load by taking the second mill out of service is a recommended option. Taking the second mill out of service while maintaining the same boiler load reduced  $\text{NO}_x$  emissions at both high (140 MW) and low (110 MW) boiler loads, possibly due to longer residence times in the primary combustion zone.

Changes in air flow resulted in measurable changes in both  $\text{NO}_x$  reduction and LOI. An increase in the reburn coal transport air (top burner primary air), corresponding to a 20% increase in the air-to-fuel ratio from 2.05 to 2.45, increased  $\text{NO}_x$  emissions from 0.28–0.31 lb/10<sup>6</sup> Btu. This increase in  $\text{NO}_x$  was attributed to less reducing

reburn zones with the additional introduction of an oxidant with the reburn fuel. Increasing the top level auxiliary airflow increased both  $\text{NO}_x$  emissions and LOI. This increase in  $\text{NO}_x$  was attributed to less reducing reburn zones as more oxidant was introduced through the auxiliary air nozzle situated directly below the reburn coal nozzle. The increase in LOI from increasing the top level auxiliary airflow was attributed to lower excess air levels in the primary combustion zone as more air was diverted away from the lower burners. Increasing the economizer  $\text{O}_2$  generated the classical response of higher  $\text{NO}_x$  emissions and lower or stable LOI. The economizer  $\text{O}_2$  sensitivity was estimated at 0.1 lb  $\text{NO}_x/10^6$  Btu per 1% change in  $\text{O}_2$  and was relatively independent of the reburn coal fineness.

The SOFA and main burner tilts had minimal effects on performance. Variations in the SOFA tilt between 0 and 15 degrees (above horizontal) had minor effects on both  $\text{NO}_x$  emissions and LOI in both LNCFS III<sup>TM</sup> and reburn configurations. Operating the main burner tilt slightly below the horizontal (about -5 degrees) improved the reburning performance (lower LOI without increasing  $\text{NO}_x$ ), relative to the horizontal setting, which was attributed to longer residence times in the furnace prior to overfire air introduction. Overall, the effect was difficult to quantify due to the limited number of tests.

At Kodak Park, the application of micronized coal reburning reduced  $\text{NO}_x$  emissions and increased LOI, as expected. Micronized coal reburning with 17.3% reburn fuel at a reburn stoichiometry of 0.89, reduced  $\text{NO}_x$  emissions to 0.59 lb/ $10^6$  Btu from a baseline of 1.36 lb/ $10^6$  Btu, a 59% reduction, and reduced the boiler efficiency from 87.8% to 87.3%. At greater reburn rates, further  $\text{NO}_x$  reduction was achieved to a degree comparable with gas reburning systems. At full load, LOI was 40–45%, compared with a baseline level of 10–12%.

Based on long-term testing, the achievable annual  $\text{NO}_x$  emissions (at 15.6% reburn or stoichiometry of 0.90) were  $0.69 \pm 0.03$  lb/ $10^6$  Btu (95% confidence), corresponding to an LOI of  $38\% \pm 2\%$ . Higher reburn feeds (estimated at 18.4% reburn or stoichiometry of 0.87) would be required for long-term compliance with the 0.6 lb/ $10^6$  Btu  $\text{NO}_x$  emissions limit.

The reburn stoichiometry had a significant effect on  $\text{NO}_x$  emissions and a significant effect on the LOI. Lower reburn stoichiometries reduced  $\text{NO}_x$  emissions and increased the LOI, typically dropping below 0.6 lb/ $10^6$  Btu at reburn stoichiometries below 0.9 and corresponding to 40–45% LOI. The increase in the LOI relative to baseline was partially due to a lower cyclone heat input, which resulted in lower temperatures in the primary combustion zone. The lower temperatures produced less thermal  $\text{NO}_x$  formation and less efficient char burnout. The LOI increase was also partially due to the staged combustion resulting in shorter residence times under oxidizing conditions. At constant heat input levels, the LOI was not significantly different with or without reburning, suggesting that in reburn applications, the LOI could be maintained at levels similar to baseline by maintaining a high cyclone heat input. The contribution of reburning alone (assuming no change in the cyclone heat input) to the increase in the LOI was estimated at 0–12% (absolute).

### Economic Performance

Estimates were prepared for retrofitting micronized coal reburning on generic 300-MWe tangentially fired and cyclone boilers. For the tangentially fired boiler, the capital costs were estimated at \$4.3 million, or approximately \$14/kW (1999\$). The O&M costs were estimated at \$0.30 million per year (1999\$). Costs were levelized both on a current dollar and constant dollar basis. The 15-year levelized cost for the 300-MWe unit is \$1,329/ton of  $\text{NO}_x$  removed on a current dollar basis, and \$1,023/ton of  $\text{NO}_x$  removed on a constant dollar basis (1999\$).

For the cyclone boiler, the estimated capital cost is \$16.9 million, or approximately \$56/kW (1999\$). The estimated O&M costs are \$0.80 million per year (1999\$). The total 15-year levelized cost is \$741/ton of  $\text{NO}_x$  removed on a current dollar basis or \$571 on a constant dollar basis (1999\$).

### Commercial Applications

Micronized coal reburning technology can be applied to existing and greenfield cyclone-fired, wall-fired, and tangentially fired pulverized coal units. The technology reduces  $\text{NO}_x$  emissions by 20–59% with minimal furnace modifications for existing units.

The availability of a coal-reburning fuel, as an additional fuel to the furnace, enables switching to lower heating-value coals without boiler derating. Commercial units can achieve a turndown of 8:1 on nights and weekends without consuming expensive auxiliary fuel.

### Contacts

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### References

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